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Evaluation of Self-Organizing Systems

Self-Organization

07.11.2011

Dr.-Ing. Abdalkarim Awad

Two Types of Evaluation

- Application dependent
 - Localization error
 - Path length
 - Collision
 - Communication overhead
 -
- Application independent
 - Autonomy
 - Adaptivity
 - Resilience
 - Decentralization
 -

Two Types of Evaluation

- Application dependent
 - Localization error
 - Path length
 - Collision
 - Communication overhead
 -

- Application independent
 - Autonomy
 - Adaptivity
 - Resilience
 - Decentralization
 -

To explore self-organizing properties of the system!

When can we describe a system as self-organizing?

When can we describe a system as self-organizing?

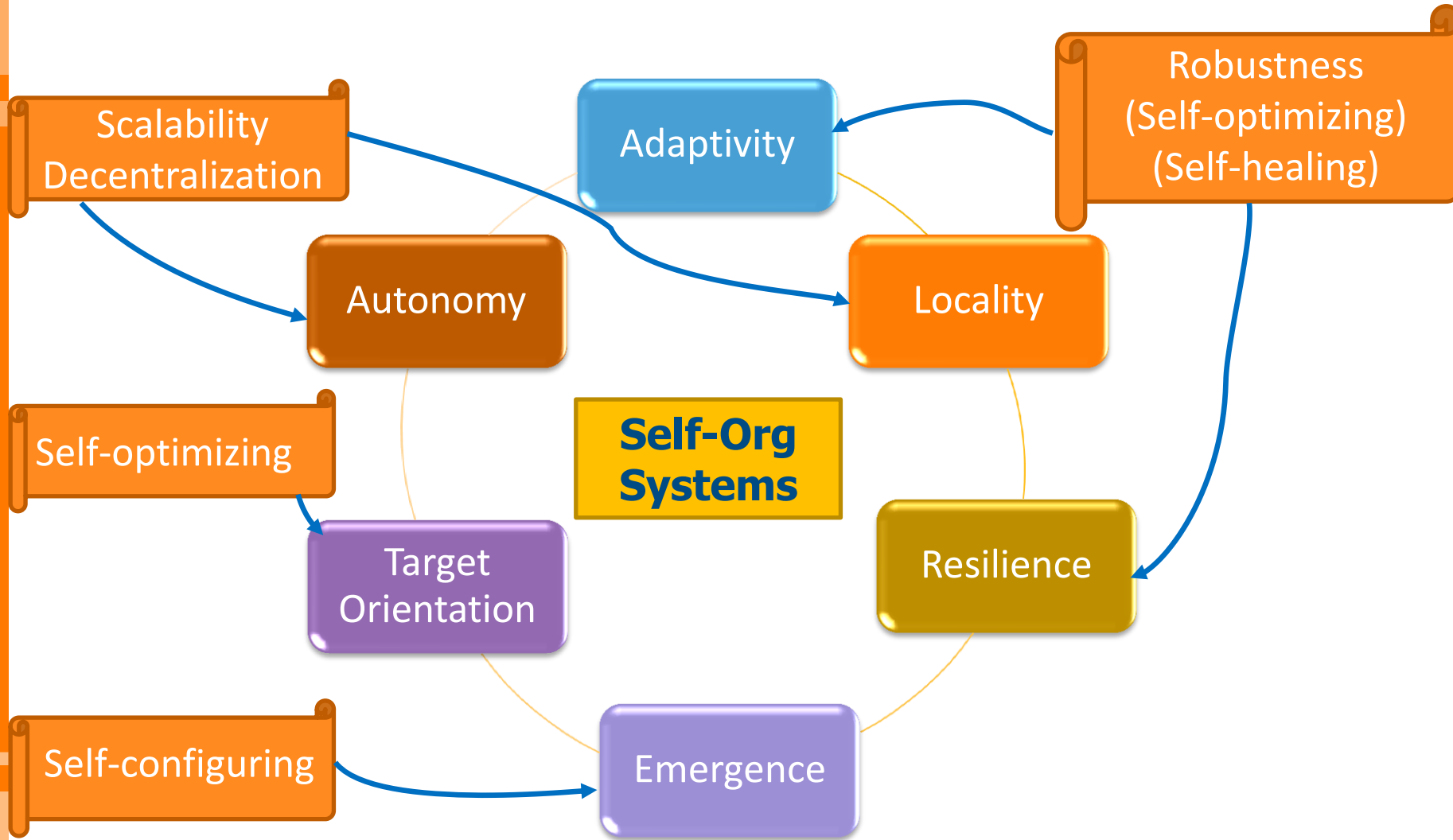
~~Self-organizing 1~~
~~Self-disorganizing 0~~



Characteristics of Self-Organizing Systems



Characteristics of Self-Organizing Systems



Characteristics of Self-Organizing Systems



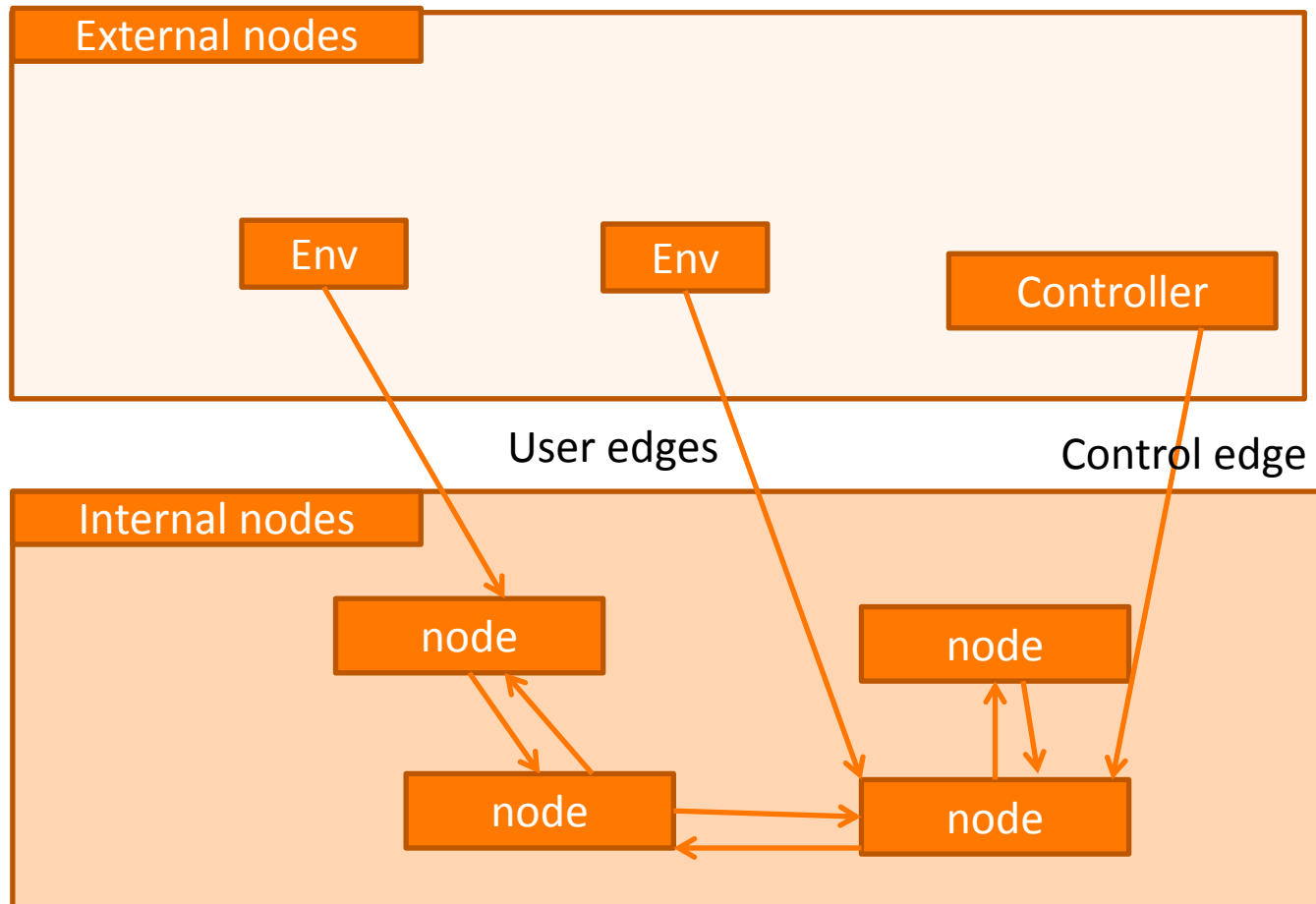
Quantitative Measures

- Degree of Autonomy
 - Refers to the amount of control data required from external entities to keep the system running.
- Degree of Emergence
 - Indicates how many globally coherent patterns or structures are induced by local interactions.
- Degree of Target Orientation
 - Indicates how the system fulfill a given purpose (high level goal).
- Degree of Locality
 - Indicates how much information does a single node have about the global state?

Quantitative Measures-More

- Degree of Adaptivity
 - How fast the system recovers after changes in the environment?
- Degree of Resilience
 - How fast the system recovers after unexpected disruptions (e.g. break down of nodes, attacks by an intruder, ...)?
- Degree of Flexibility
 - In self-organizing systems all nodes has the same importance, therefore there is no single point of failure.
- Degree of Reliability
 - self-organized algorithm should be able to find alternative solutions if they are exist.

Example



Quantitative Measures Using Information Entropy

- To measure **self-organizing properties** of a system, we can use the **quantity of information** in the system.
- Statistical Entropy of a random variable X:

$$H(X) = - \sum P(X = w) \log_2 P(X = w)$$

- With this concept we can measure for each point of time
 - the information in the **whole system**
 - the information on the **internal edges**
 - the information on the **input edges**
 - the information on the **control edges**
 - the information on the **output edges**

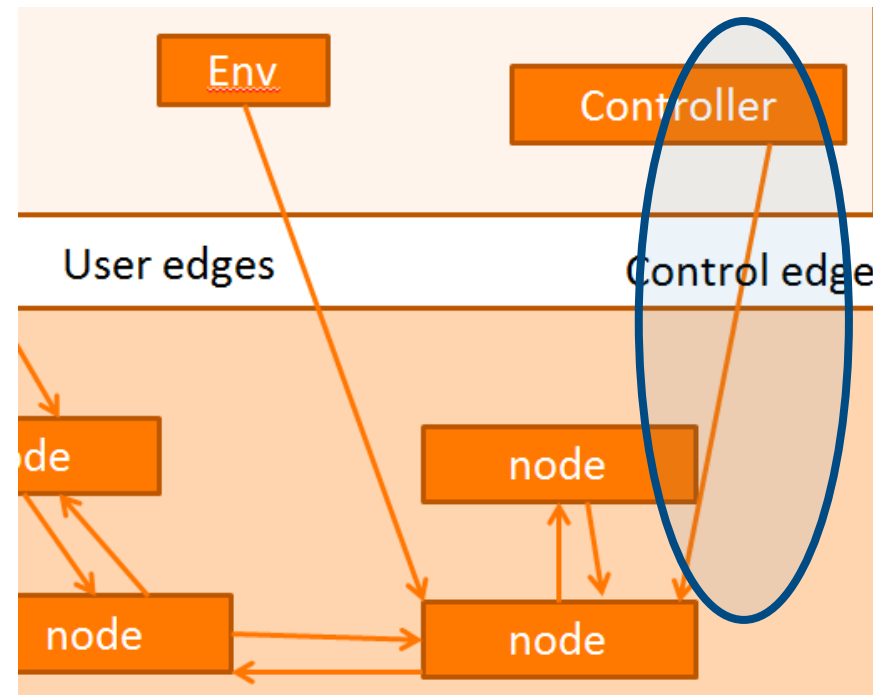
Degree of Autonomy $\alpha \in [0, 1]$

- Compare the information contained in the control edges with the information contained in all edges during the whole run of the system.

$$\alpha = 1 - (H(\text{values on control edges}) / H(\text{values on all edges}))$$

$\alpha \approx 1$ high level of autonomy
(relatively few control data)

$\alpha \approx 0$ low level of autonomy
(relatively much control data)



Degree of Emergence $\varepsilon \in [0, 1]$

- Compute the dependencies between values on the edges.
- Compare the information contained in all edges with the sum of the information contained in each single edge.

$$\varepsilon = 1 - (H(\text{values on all edges}) / \sum_{k \in K} H(\text{Value on } k))$$

$\varepsilon \approx 1$ high level of emergence
(many dependencies)

$\varepsilon \approx 0$ low level of emergence
(few dependencies)



Source: Wikipedia

Quantitative Measures Using upper bound

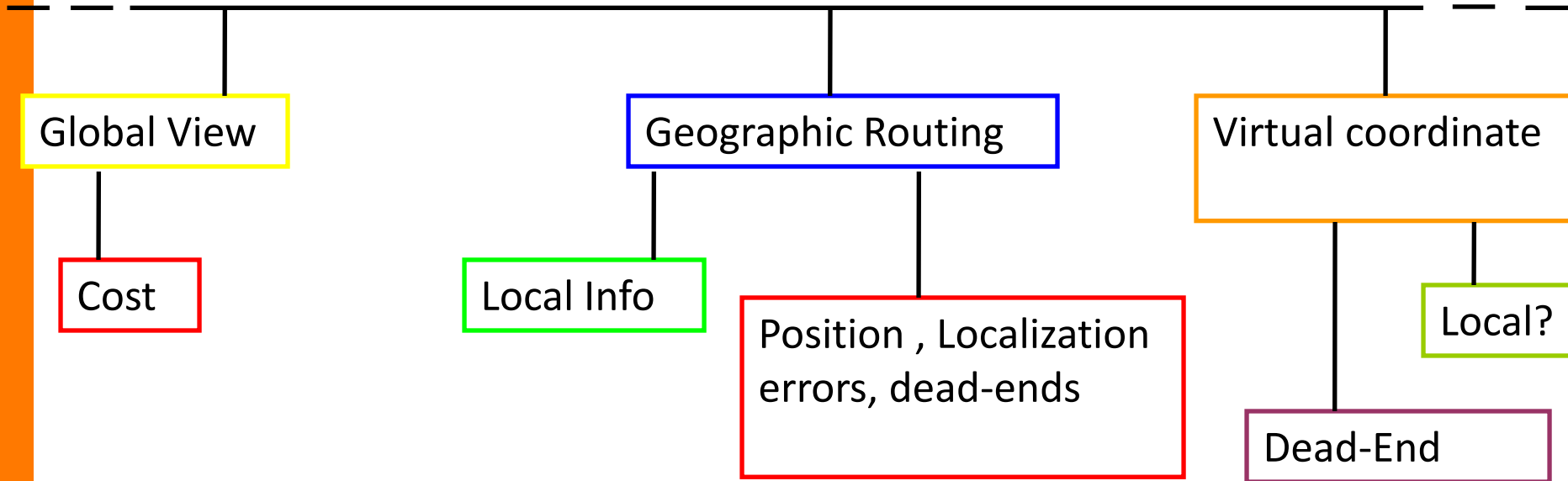
- To measure **self-organizing properties** of a system, we can partially rely on the **big O notation known from complexity theory** to measure the amount of messages required in a function.
- A self-organizing system produces complex organization from randomness based on local interaction and without external intervention. Therefore the optimal complexity is

Optimla number of message $=O(m)$
, wher is a constant(node degree)
and independant of network size(n)

Quantitative Measures-Routing Protocols

- Degree of Scalability
 - Complexity of Autonomy + Complexity of locality
- Degree of Robustness
 - Complexity of Adaptively + complexity of resilience
- Degree of Target Orientation
 - Path length (optimal Shortest path)

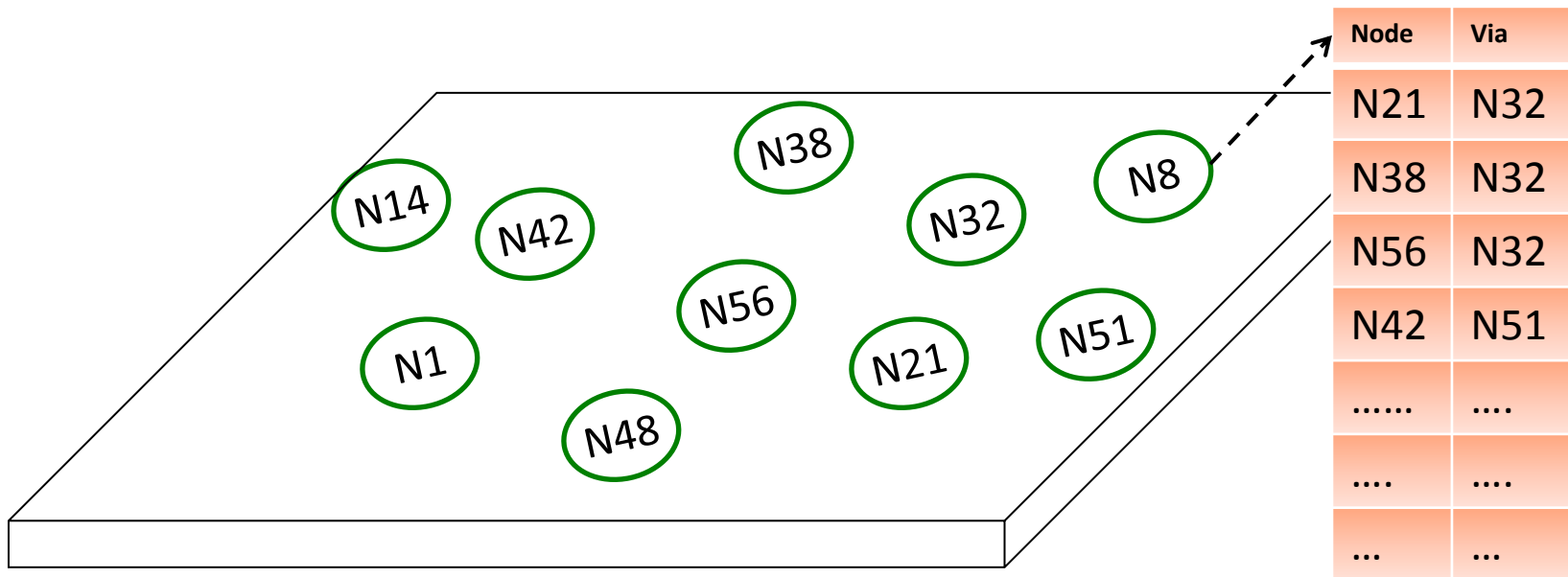
Routing in Wireless Sensor Networks



Routing in Wireless Sensor Networks

Global view of the entire network

cost

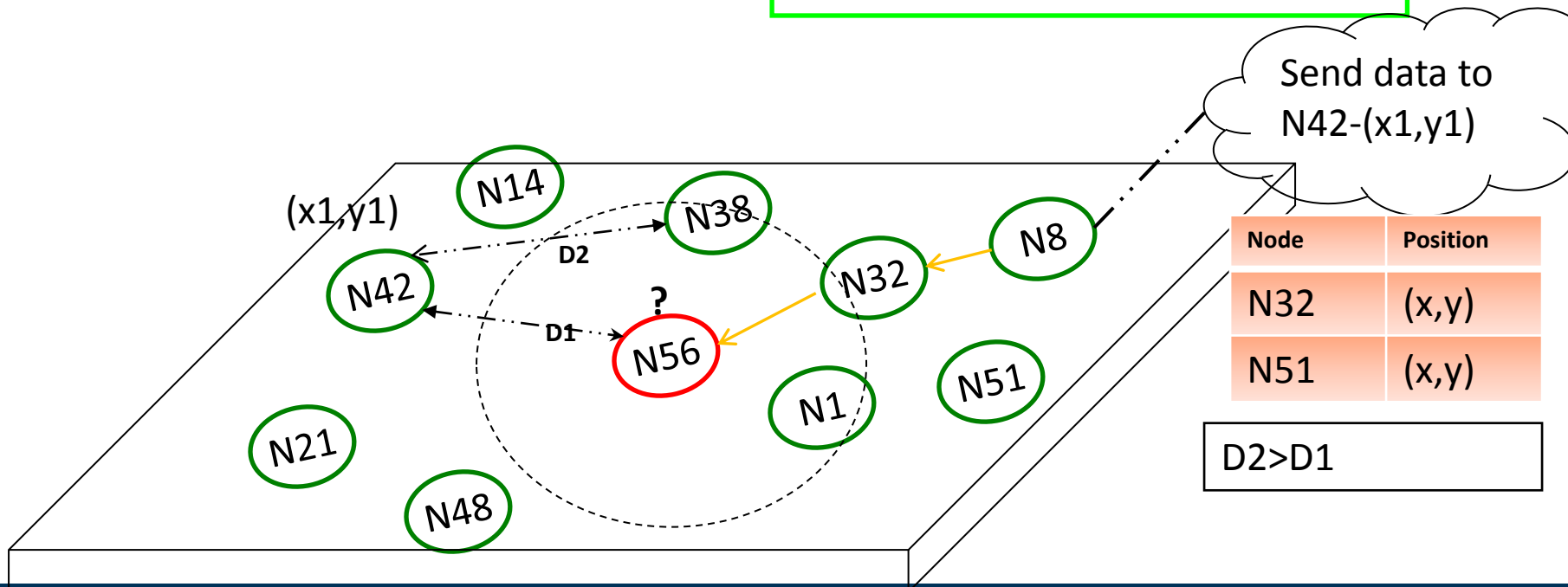


Routing in Wireless Sensor Networks

Geographic Routing

Position, localization errors, Dead ends

Local information

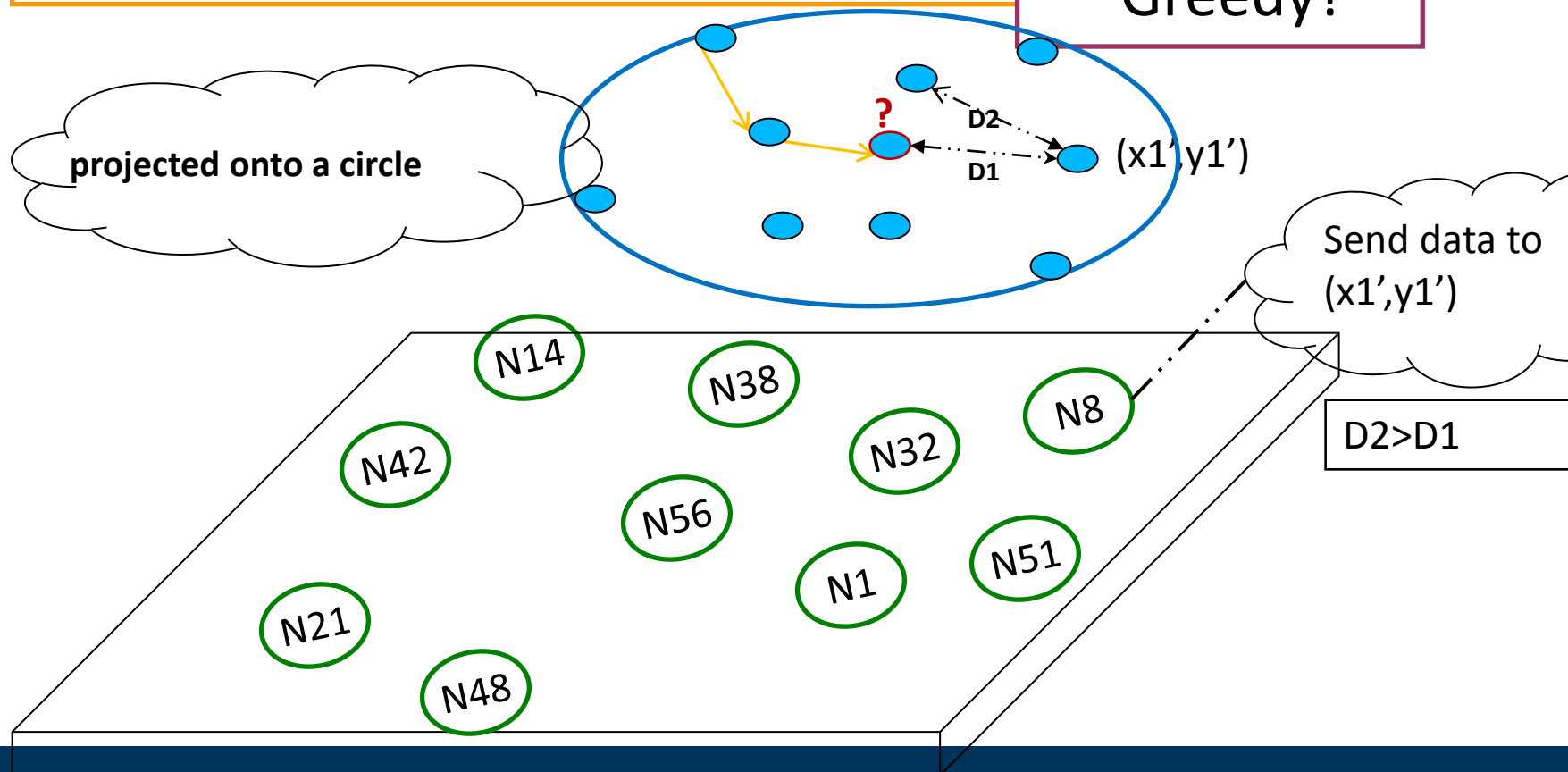


Routing in Wireless Sensor Networks

Virtual coordinate

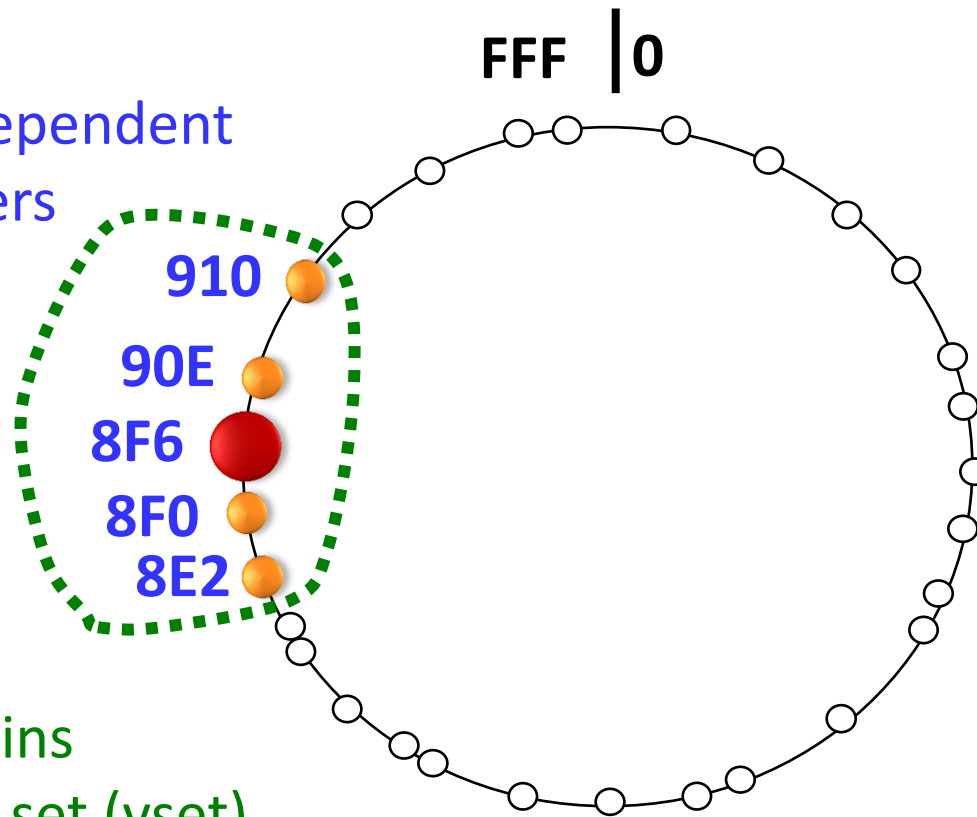
cost?

Greedy?



VRR: The Virtual Ring

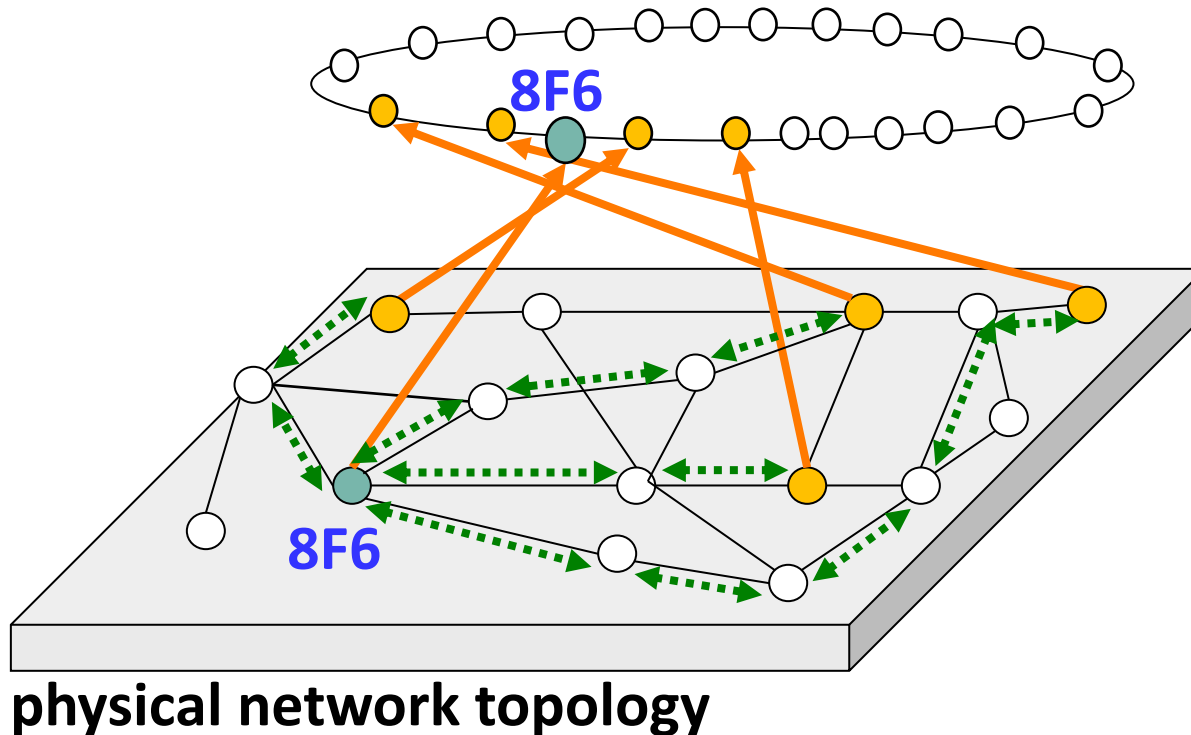
Topology-independent
node identifiers



Each node maintains
a virtual neighbor set (vset)

Nodes organized into virtual ring
by increasing identifier value

VRR: Routing paths



Nodes only maintain routing paths to virtual neighbors:

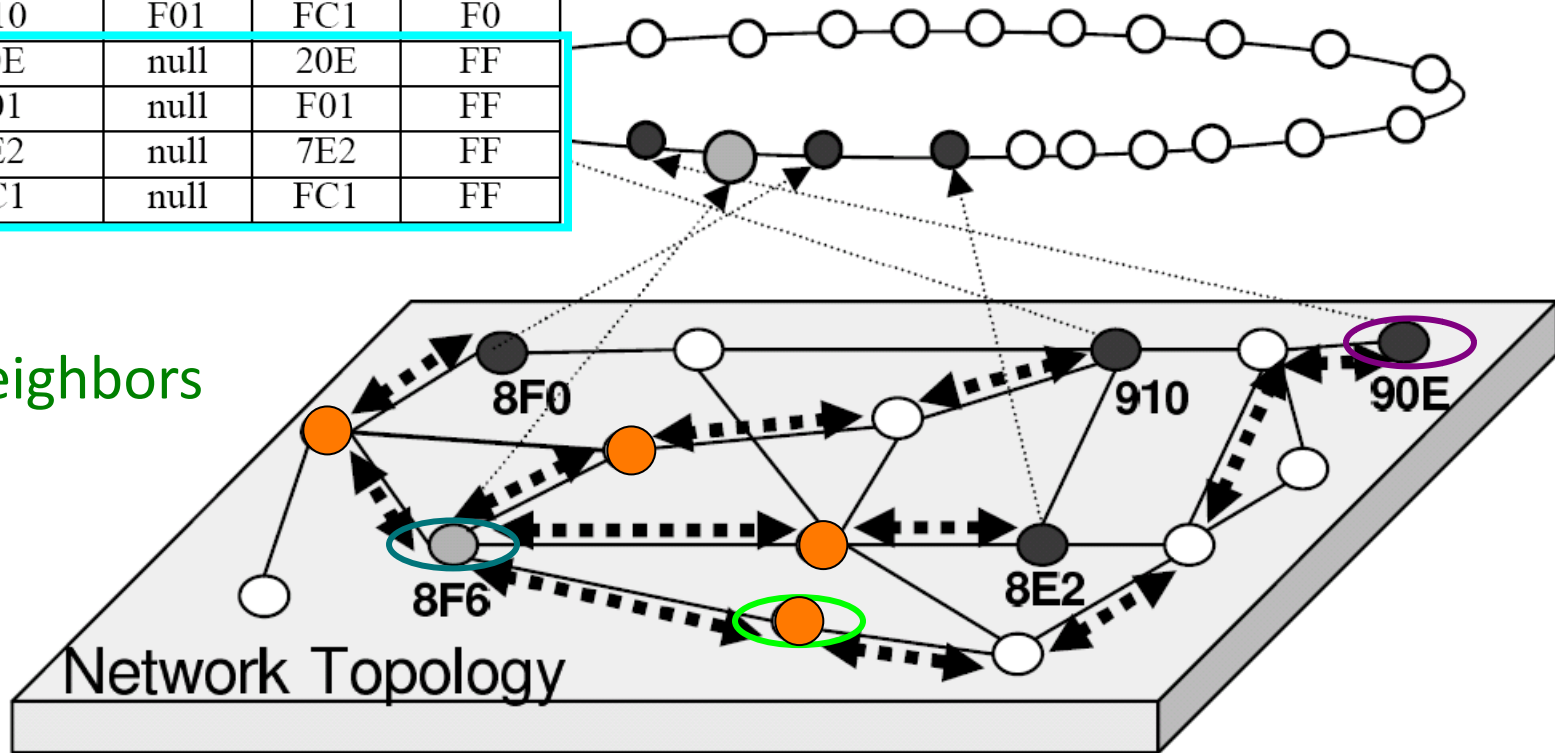
- Paths maintained proactively
- Paths are bidirectional and typically multi-hop

Routing Table

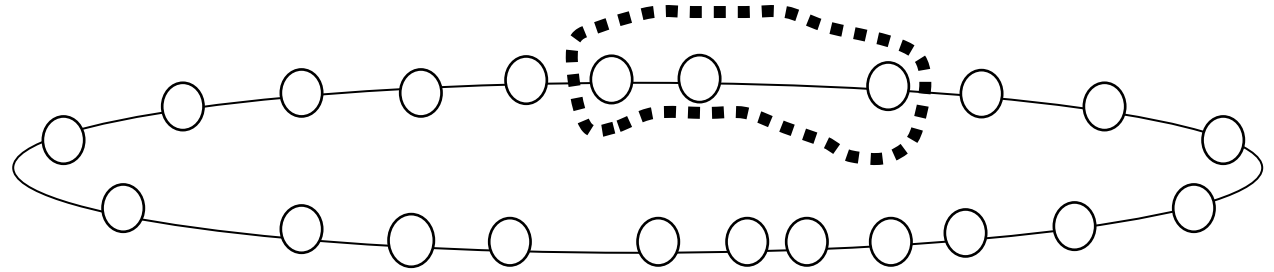
endpoint _A	endpoint _B	next _A	next _B	path id
8F0	8F6	20E	null	03
8E2	8F6	F01	null	2F
8F6	90E	null	7E2	1E
910	8F6	F01	null	2F
35F	37A	20E	7E2	12
A01	A10	F01	FC1	F0
8F6	20E	null	20E	FF
8F6	F01	null	F01	FF
8F6	7E2	null	7E2	FF
8F6	FC1	null	FC1	FF

← vset

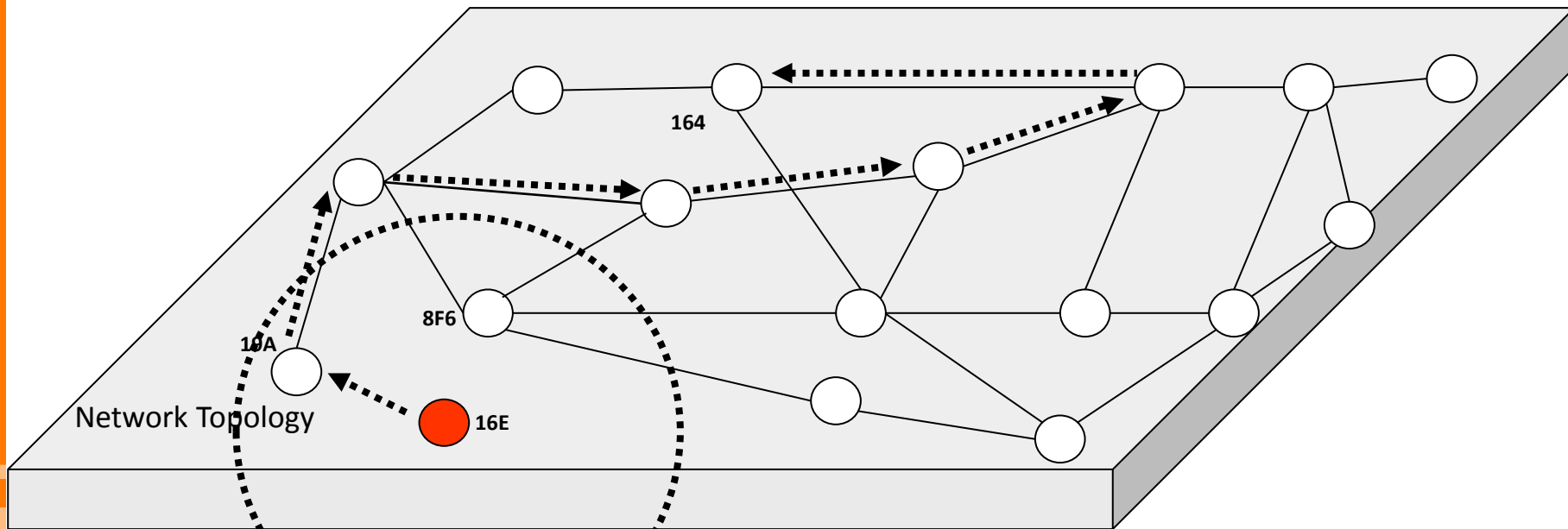
Physical neighbors



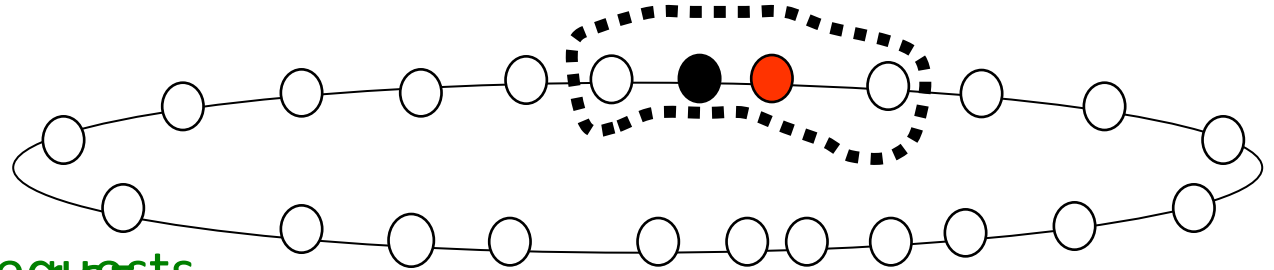
VRR: Node joining



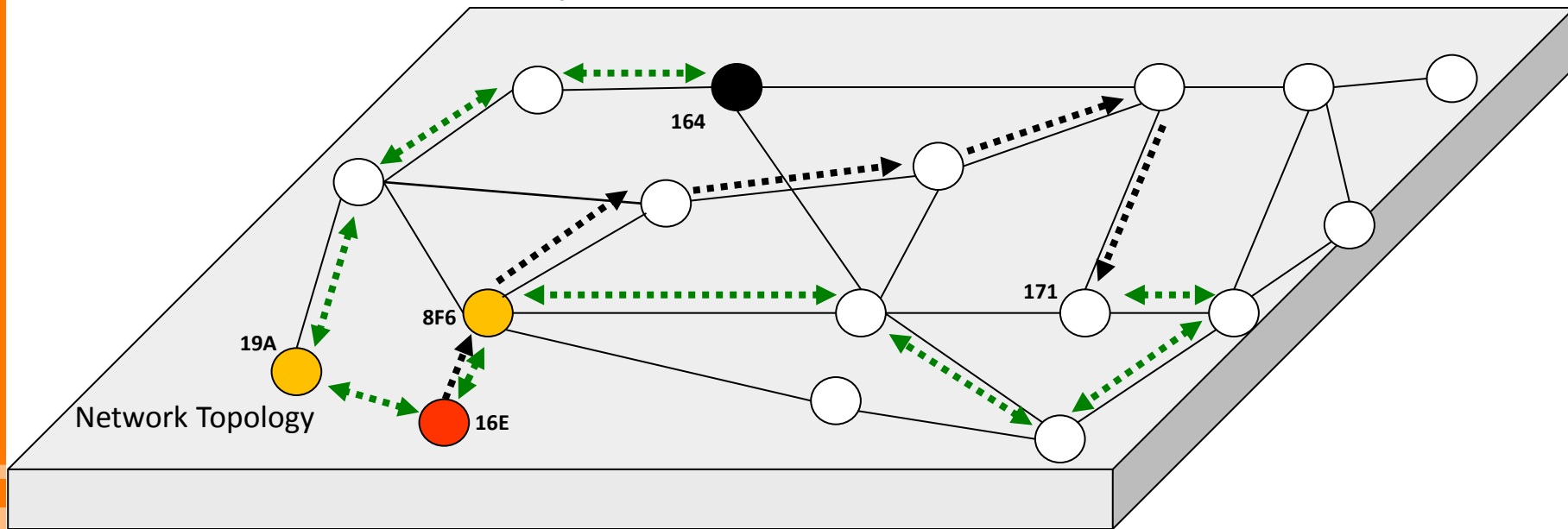
broadcast hellos
Send setup request to 16E
to find physical neighbors



VRR: Node joining

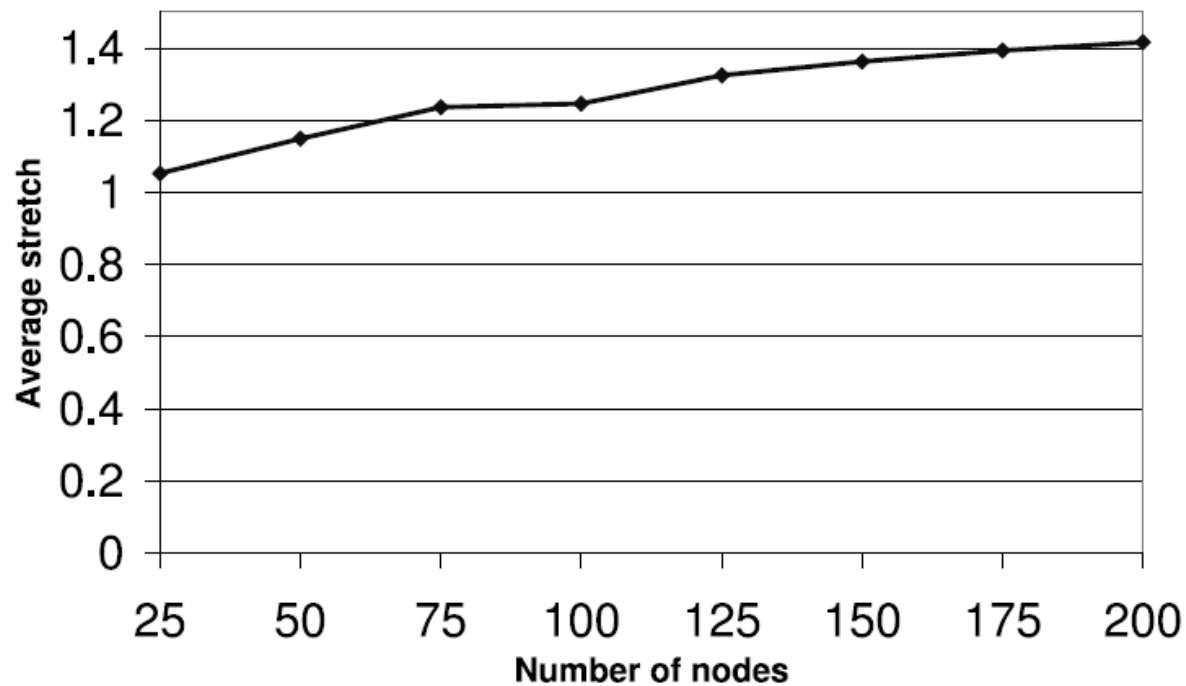


16E sends setup requests
to nodes in received vset
when it receives setup



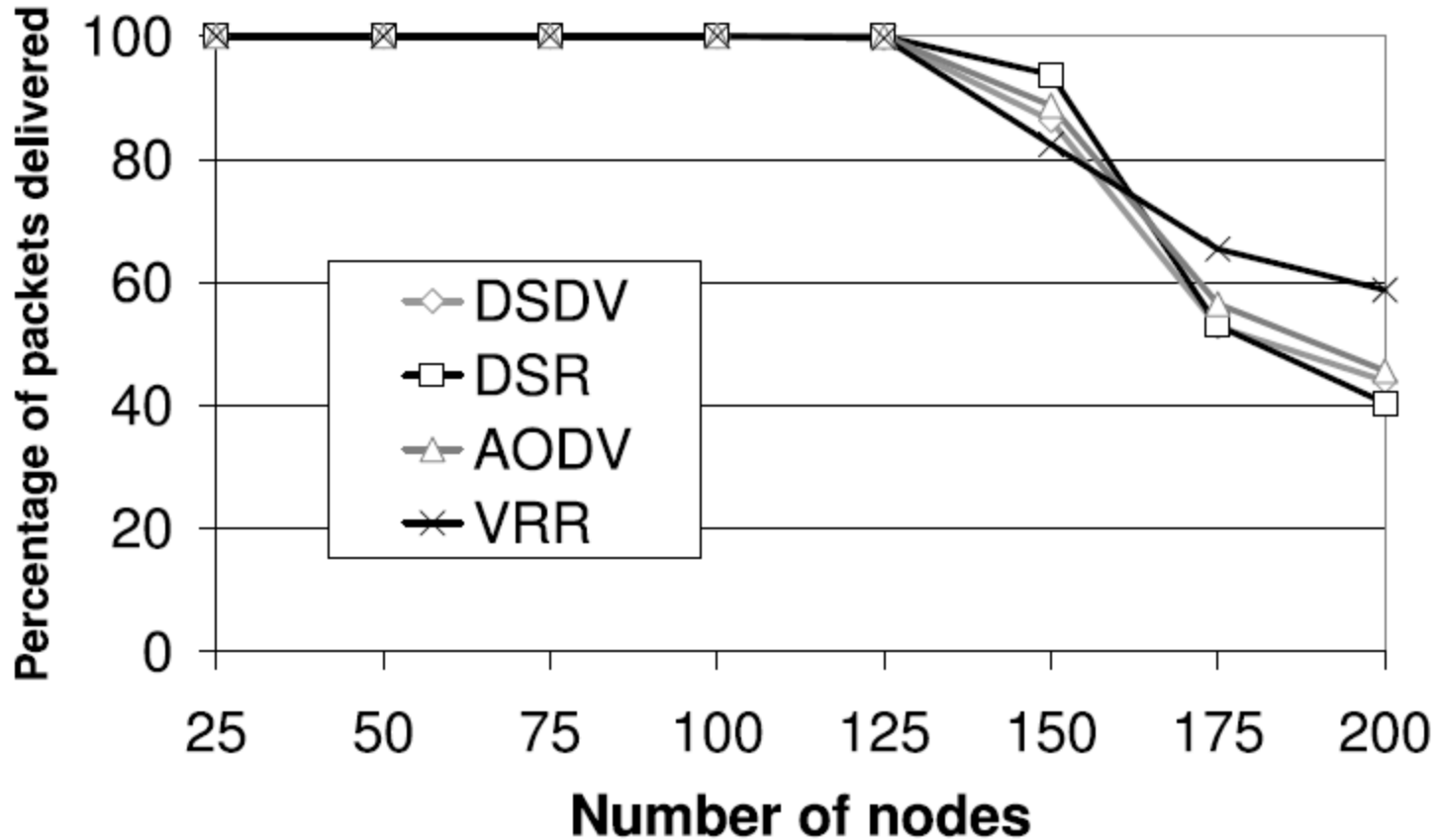
Average Stretch

Stretch ratio: the ratio between length of the path traversed by a routing protocol, in comparison with the optimal shortest paths in the network graph.



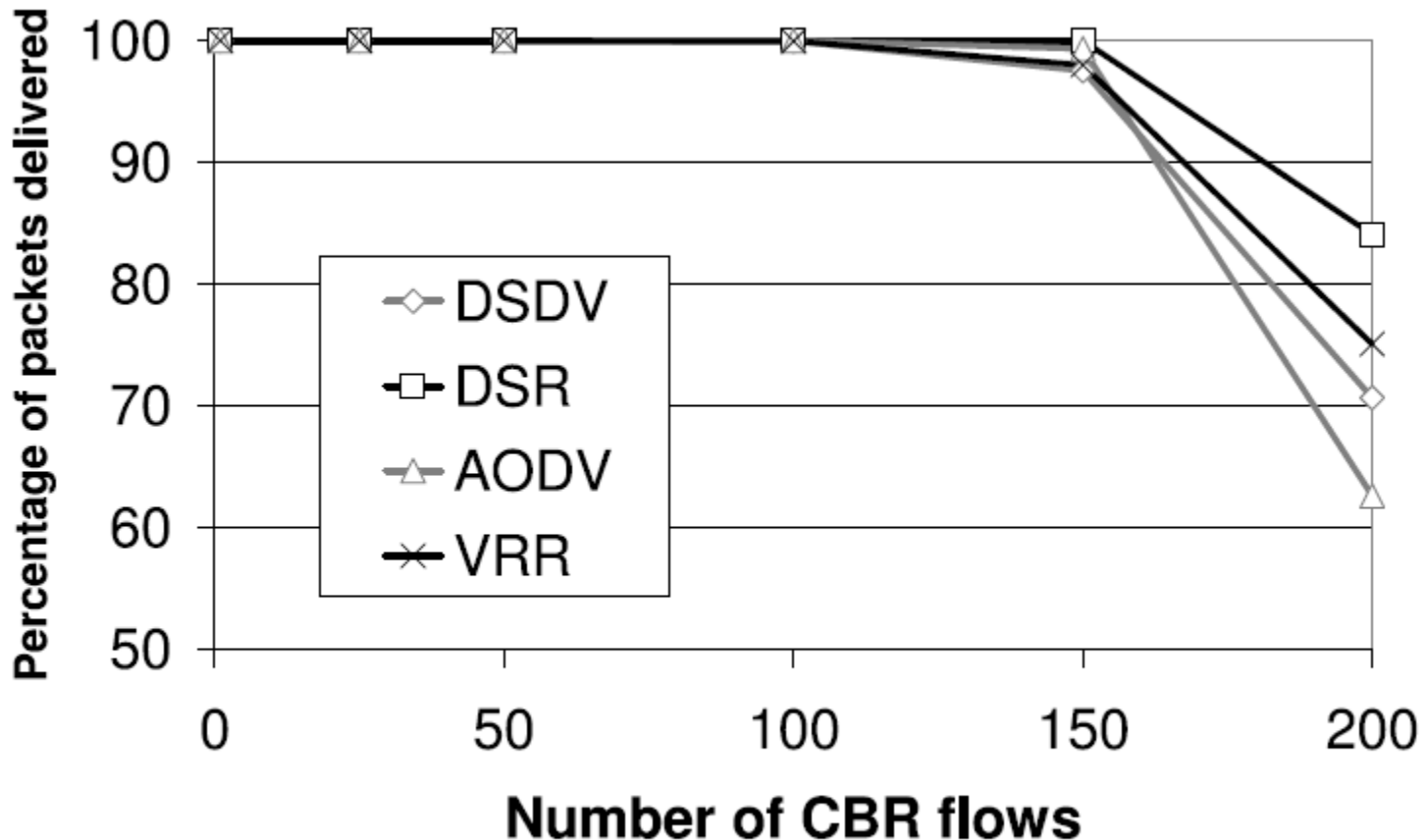
(a) Average stretch

Evaluation-Network Size (1Packet/sec)



(a) Packets delivered correctly

Evaluation-Load (100 nodes)



(a) Packets delivered correctly

Quantitative Measures- VRR

- Degree of Scalability

- Complexity of Autonomy + Complexity of locality

$$VRR_{sca} = O(m) + O(r\sqrt{n}) = O(r\sqrt{n})$$

- Degree of Robustness

- Complexity of Adaptively + complexity of resilience

$$VRR_{rob} = O(m) + O(n) = O(n)$$

- Degree of Target Orientation

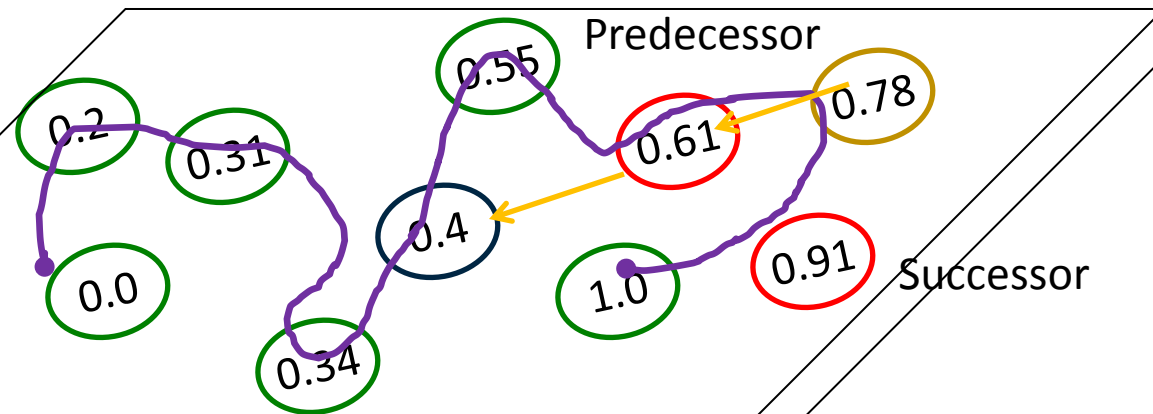
- Maximum $O(n)$
- Average $O(\sqrt{n}) + \varepsilon$

VCP(Virtual Cord Protocol)

Each Node has a relative position to some of its neighbor node(s).

pre-determined range [0,1]

Neighbor Information is used for routing



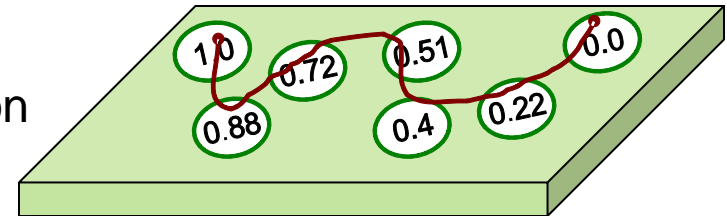
VCP – Virtual Cord Protocol

- **Cord setup**

- Assignment of virtual coordinates (or positions)
- Initial start node “S” and the range “[S, E]” are pre-defined
- Local “hello”s are used to exchange neighborhood information

- **Routing**

- Greedy along the cord
- Exploiting neighborhood information



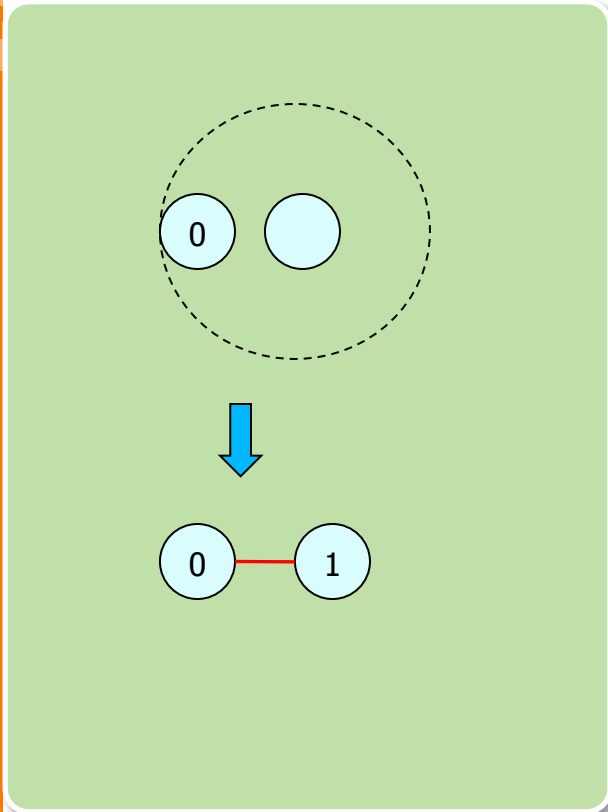
- **Data storage**

- DHT services , get , put , replicate
- Replication either on the cord or within the local neighborhood

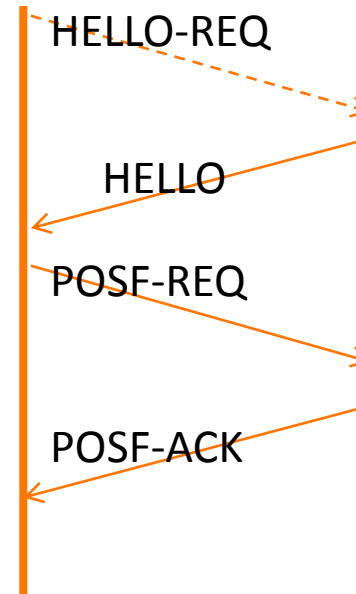
RVCP- Join

- Range $[0,1]$
- One node must be pre-programmed as initial node, i.e. it gets position 0.
- Reactive: the joining node sends a hello-request message.

RVCP- Join

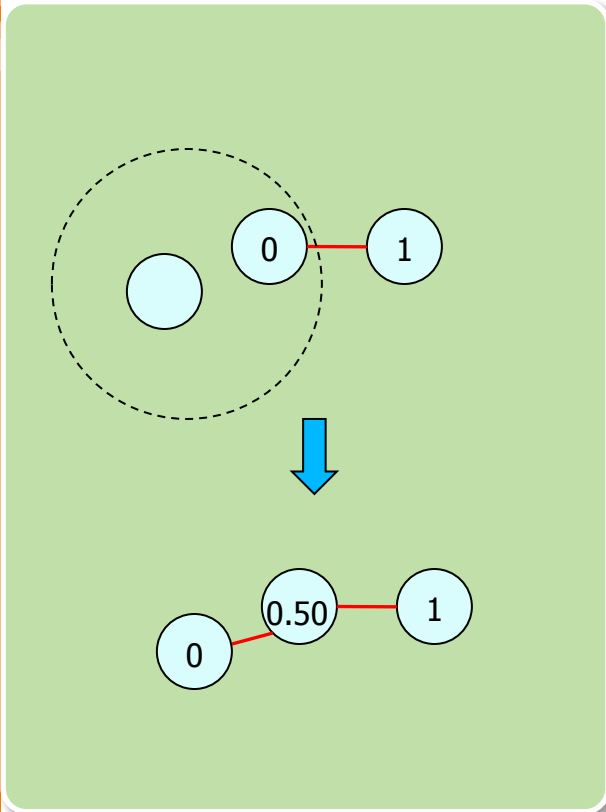


Joining Node Joined Node

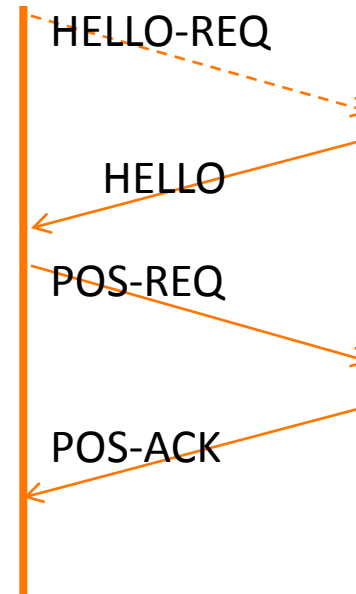


The second node gets the other end

RVCP- Join

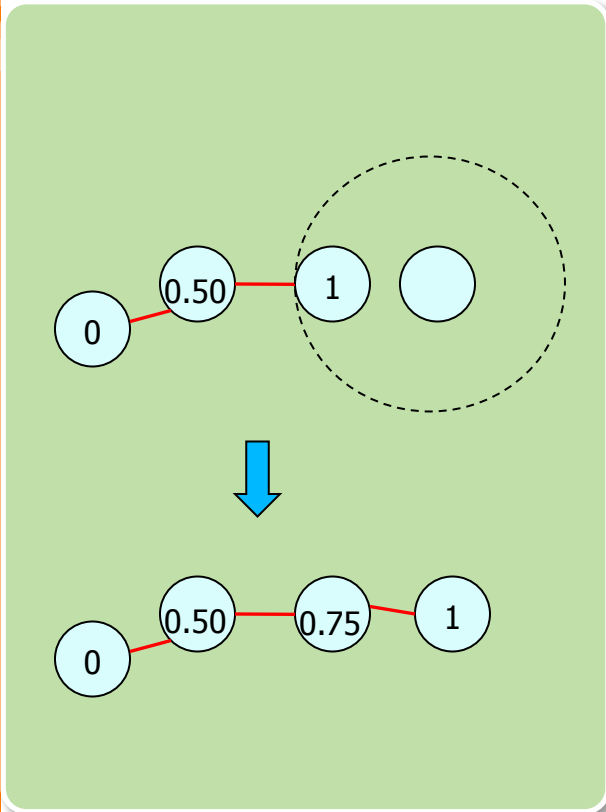


Joining Node Joined Node



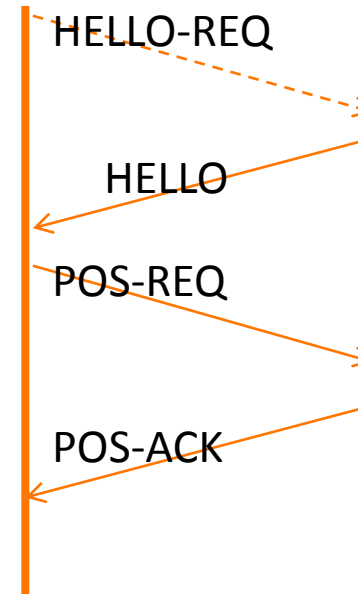
If can communicate with
an end , get that end

RVCP- Join



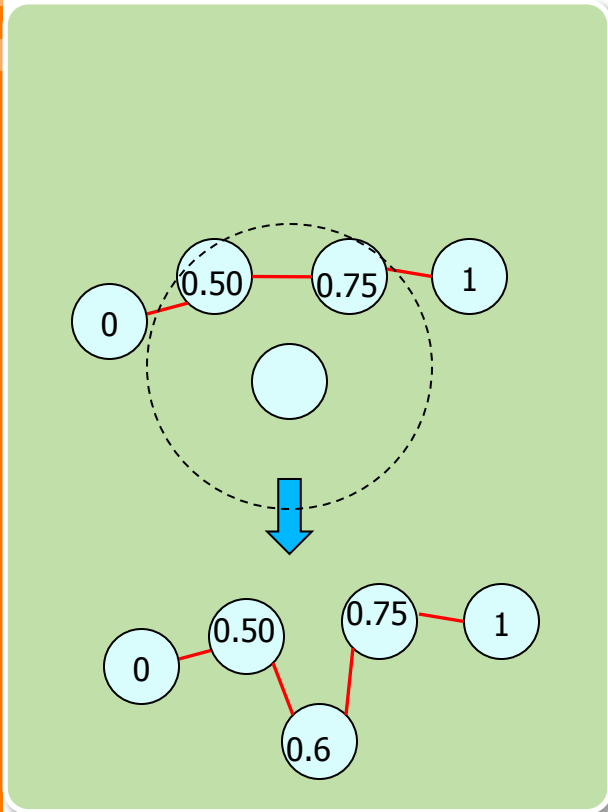
Joining
Node

Joined Node

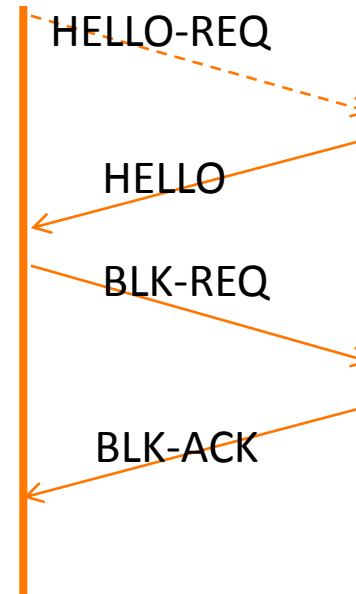


If can communicate with an
end , get that end

RVCP- Join

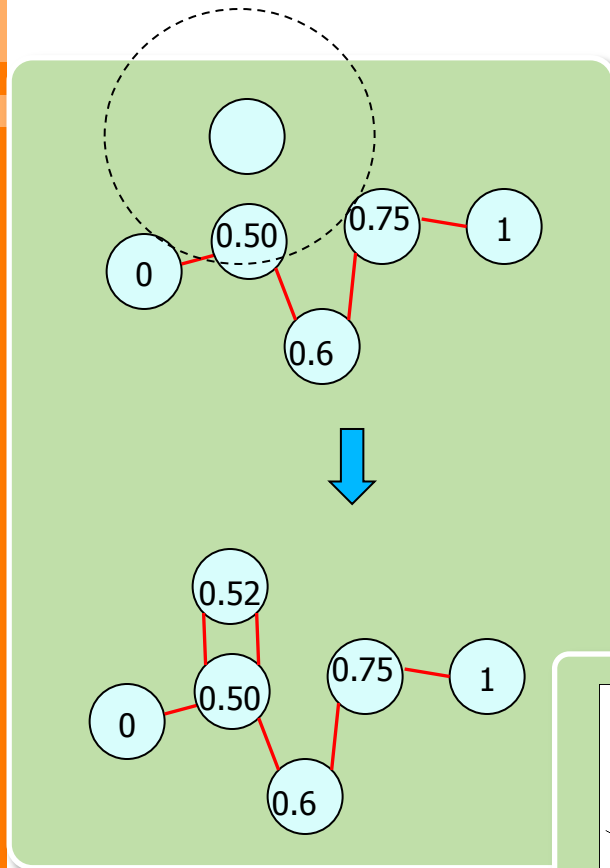


Joining Node Joined Node

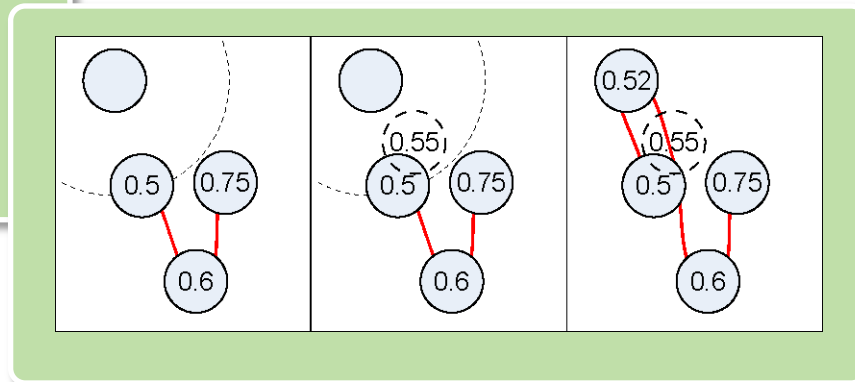


If can communicate with two adjacent nodes , get a position between them

RVCP- Join

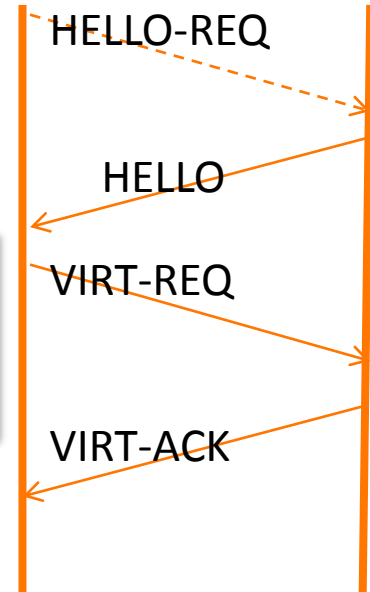


Otherwise create a virtual node

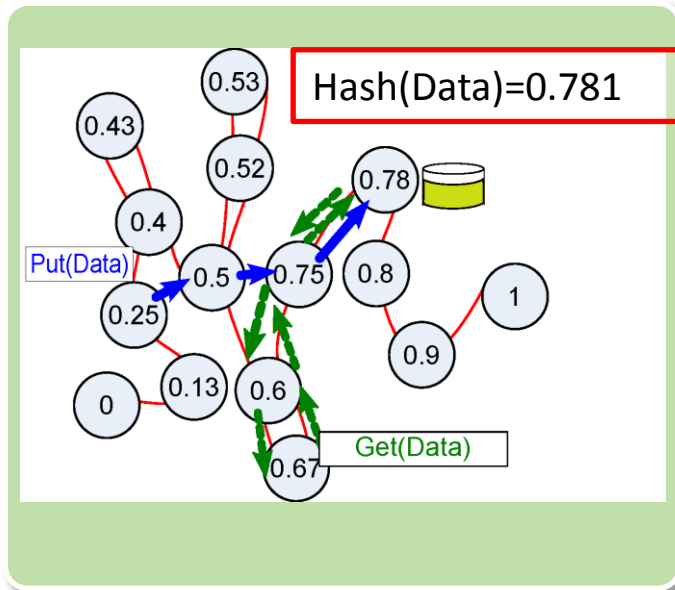


Joining Node

Joined Node



Routing using RVCP



receive a Data packet
if (stale routing info)
Send hello-req
Else
Route data

Given a static network:

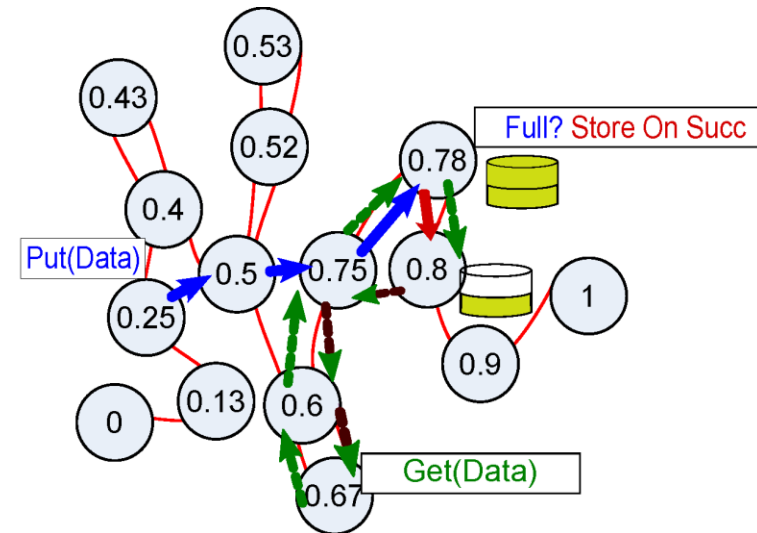
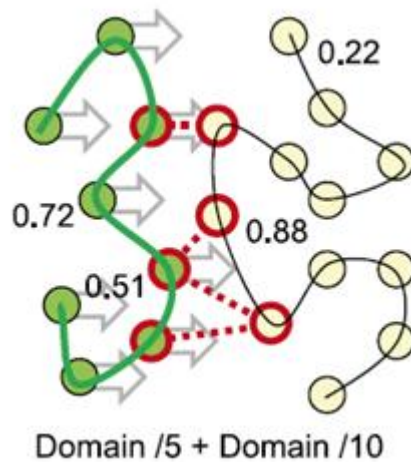
1-*Greedy* forwarding based on
local information guarantees
packet delivery

2-routing in VCP is **loop free**

Node 0.25	Neighbors
Successor 0.4	0.0
Predecessor 0.13	0.13
	0.4
	0.5 (0.55)

Additional Features

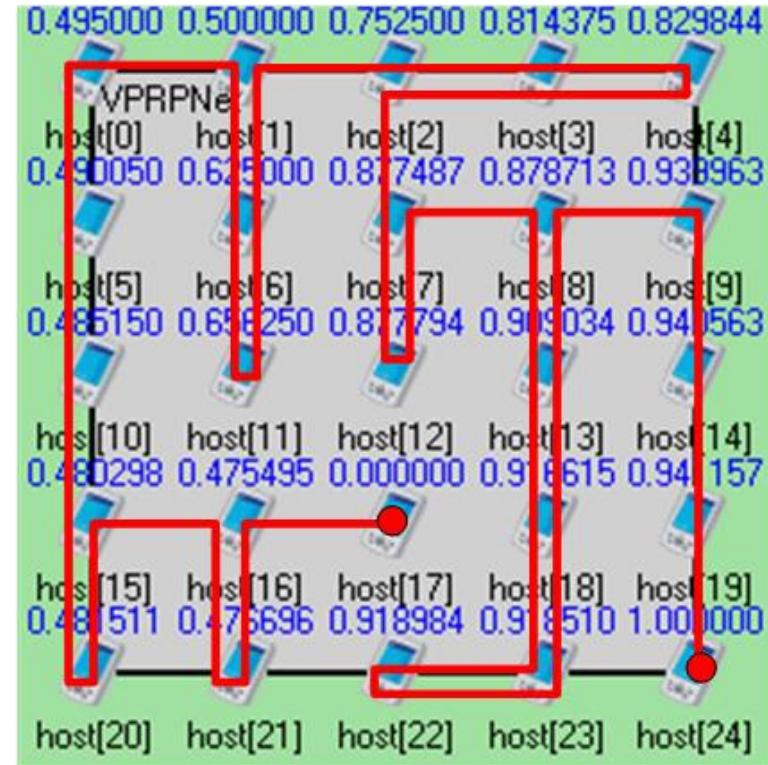
- Cooperative Storage
 - If the nodes are supposed to store data for long time, the storage capacity of an individual sensor node can get exhausted.
 - Use the successors on the cord to replicate data
 - **Bloom filters** can be used to restrict query forwarding
- Inter-domain Routing
 - Use hash function to store Gateway information (position)
 - publish-subscribe



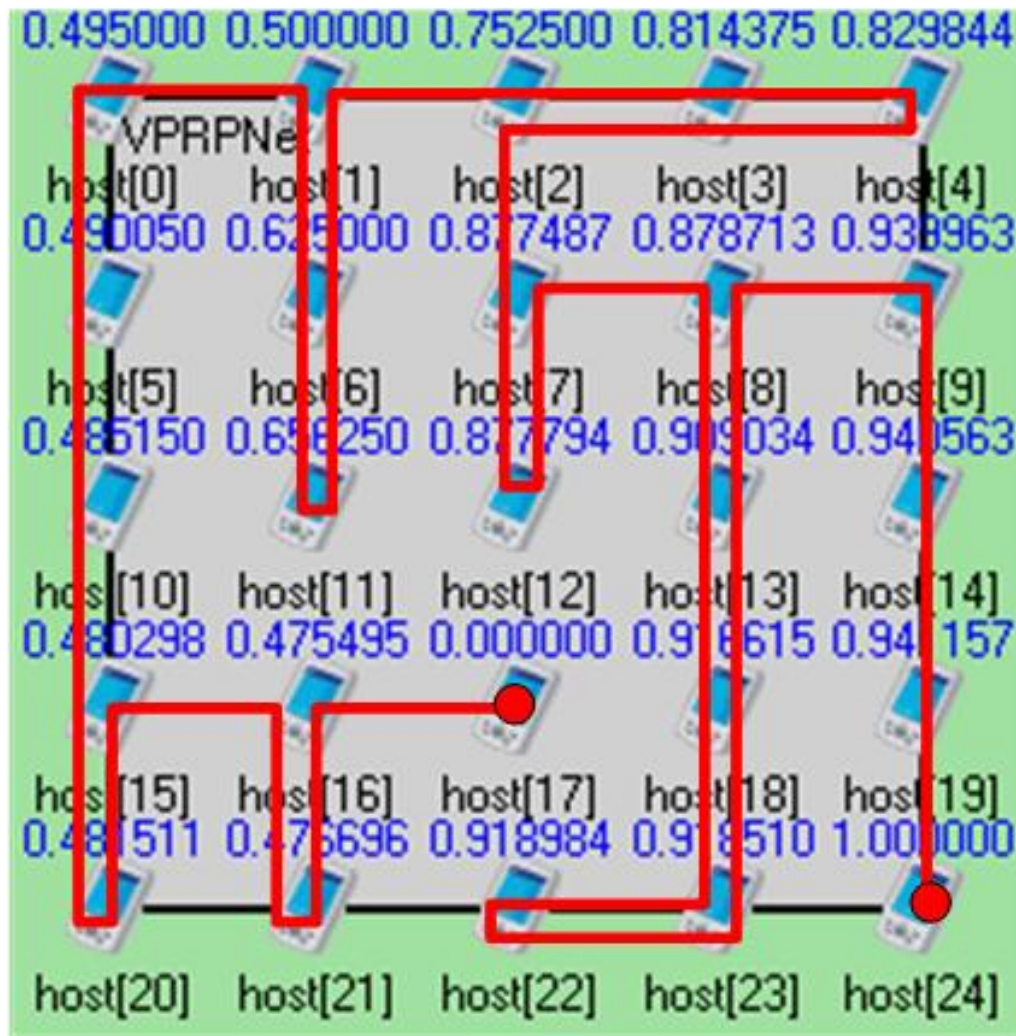
Simulation

Simulation using OMNET++
INET Framework
IEEE802.11b-complete network stack

Comparison to **DYMO**
Dynamic MANET on Demand
“Standard” IETF MANET protocol
Comparison to **VCP**
Proactive version!



Emergent phenomena



Stretch Ratio

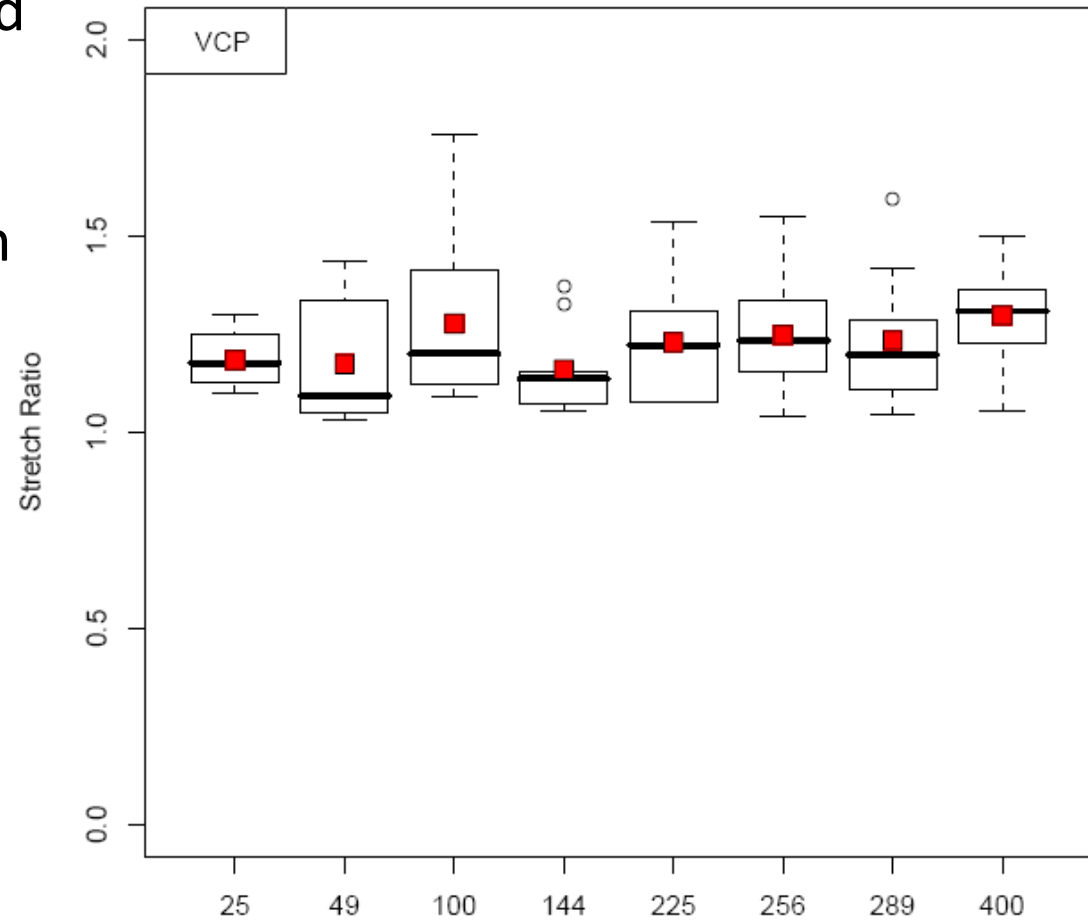
a box from the first quartile to the third quartile.

median is a thick line.

whiskers to the minimum and maximum .

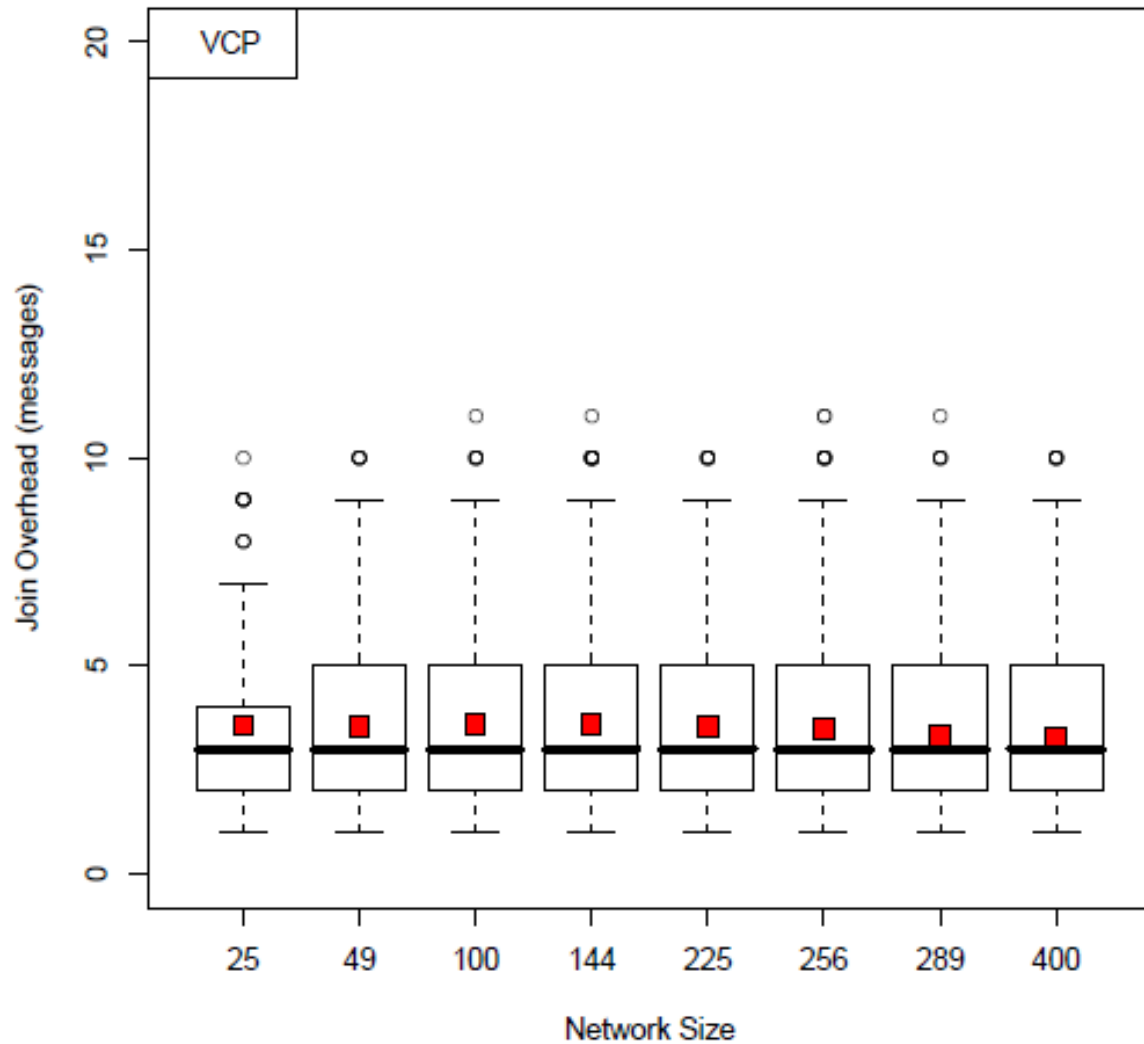
Data points outside the range of the box and whiskers are considered outliers.

The mean is the small filled square.



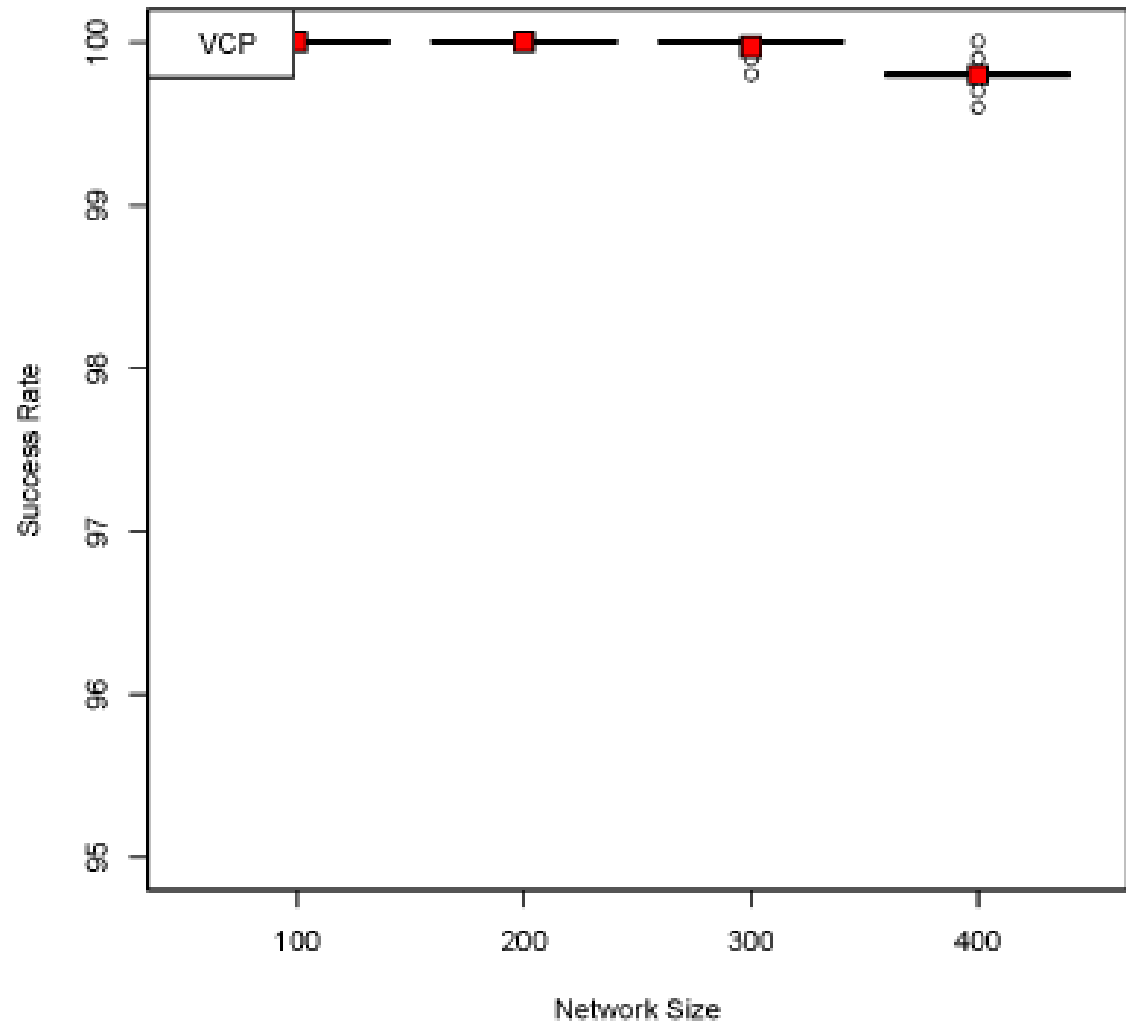
Join overhead

Number of
messages required
to join the VCP



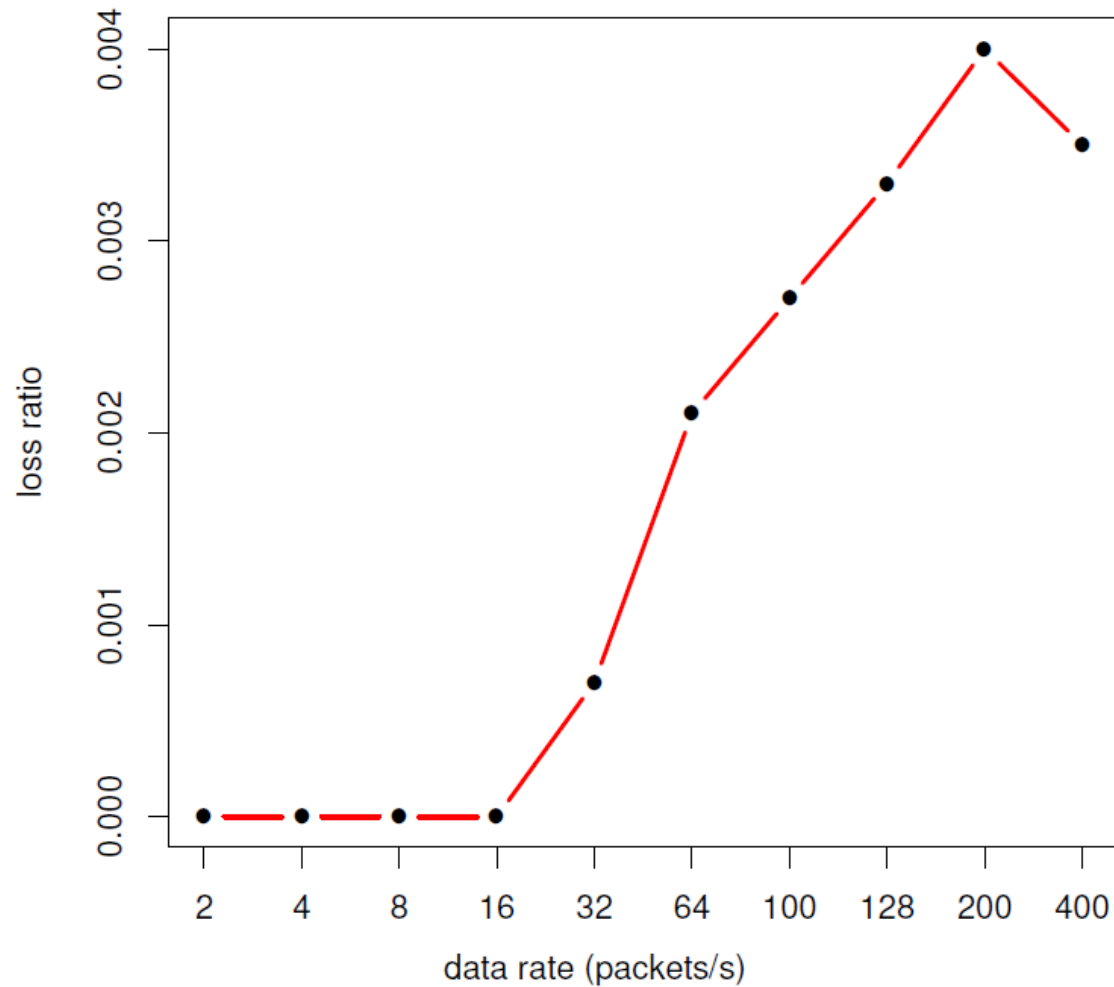
Evaluation-Network Size (1Packet/sec)

Packet Delivery ratio



Evaluation-Load (100 nodes)

Packet Delivery ratio



Quantitative Measures- VCP

- Degree of Scalability

- Complexity of Autonomy + Complexity of locality

$$VCP_{VCP} = O(m) + O(1) = O(m)$$

- Degree of Robustness

- Complexity of Adaptively + complexity of resilience

$$VCP_{rob} = O(m) + O(n) = O(n)$$

- Degree of Target Orientation

- Maximum path length $O(n)$
- Average $O(\sqrt{n}) + \epsilon$

Summary (what do I need to know)

- Understand the meaning of the different characteristics of self-organizing networks
- How entropy can be used
- What are VRR and VCP
- How the complexity can be used to measure the characteristics of Self-organizing networks

References

- Slides “Evaluation of self-organizing systems using quantitative measures ” by Hermann de Meer, Richard Holzer, Patrick Wüchner
- R. Holzer and H. Meer, “Quantitative modeling of self-organizing properties,” in Proceedings of the 4th IFIP TC 6 International Workshop on Self-Organizing Systems, ser. IWSOS '09. Berlin, Heidelberg: Springer-Verlag, 2009, pp. 149–161.
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- M. Caesar, M. Castro, E. B. Nightingale, G. O'Shea, and A. Rowstron, “Virtual Ring Routing: Network routing inspired by DHTs,” in *ACM SIGCOMM 2006*. Pisa, Italy: ACM, September 2006.